Booster RFSum Shape

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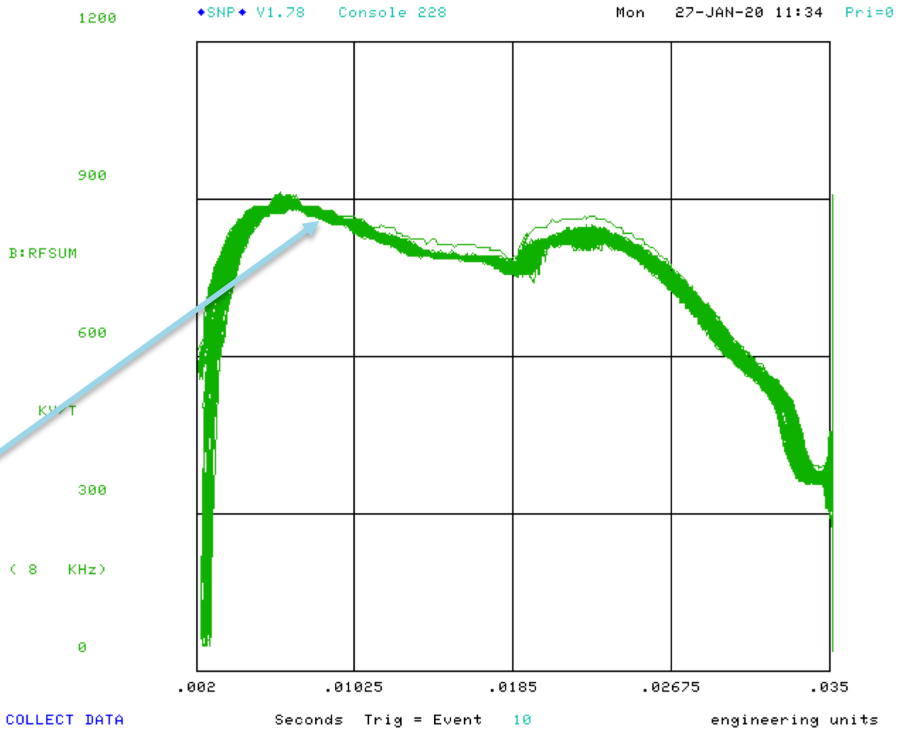
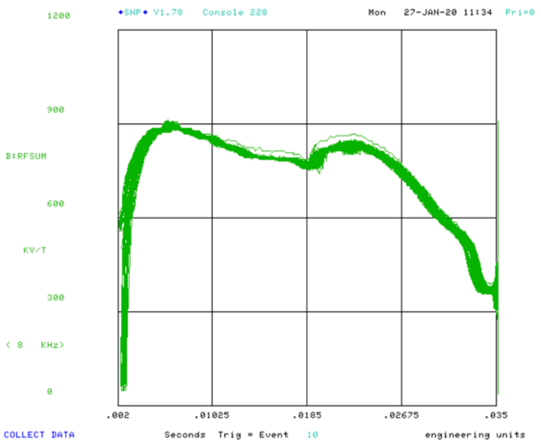
Booster RF Sum

- As I was out of operations for some time…
  - 'heard' how Booster RF was run
  - But I didn't understand it
  - So I started with RFSum and Station Counts - Using the Datalogger
    - 2018: > 1MV and 21 cavities
    - 2019: 925 kV and 20 cavities
    - Sampling at $10+8 msec
      - Which is not quite the peak!
    - January 2020: 900 kV



Beamdocs #7833 documents some history on RFSum and # Cavities

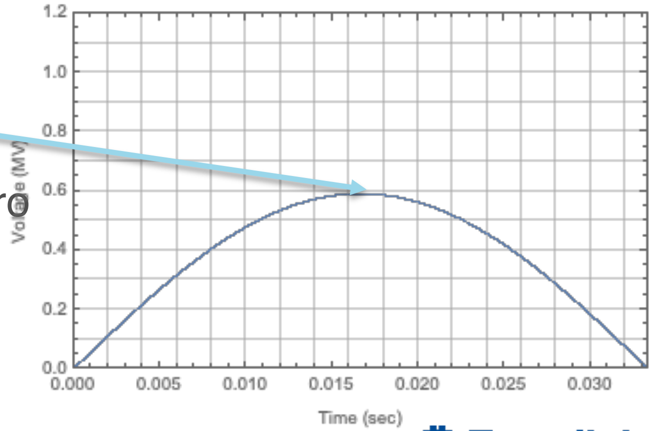
And Why does it have this shape?



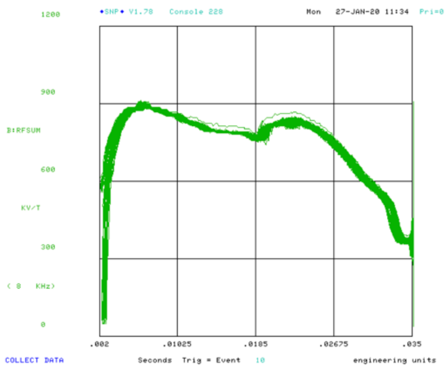
- Necessary Energy gain per turn is directly related to pdot, which is directly related to Bdot

- For this exercise: $p(t) = (p_f - p_i)Cos(2\pi f_{ramp} t) + p_i$
  - p_i = 954.26 MeV/c (E_k = 400 MeV/c^2)
  - p_f = 8888.89 MeV/c (E_k = 8 GeV/c^2)
  - f_{ramp} = 15 Hz
  - Actually want Edot not pdot
    - Peak value is 595 kV at 16.67 msec
  - Accelerating voltage (Vacc) shape for a zero intensity zero emittance beam
    - Real bucket need to include the accelerating phase

$$V_{acc} = V_{rfsum} Sin(\phi_S)$$



Real Beams have emittance!



- Accelerating Bucket needs to capture all the beam
  - Bucket area which is a function of
    - Energy
    - V_{rfsum}
    - Accelerating Phase
  - If fix the bucket area, have 2 equation in 2 unknowns (V_{rfsum} and ϕ_s)

$$\text{Bucket Area} = 16\sqrt{\frac{\beta^2 \ \mathrm{E} \ V_{rfsum}}{2\pi\omega_0^2 \ \mathrm{h} \ |\eta|}} \ \alpha(Sin(\phi_S)) \qquad V_{acc} = V_{rfsum} Sin(\phi_S)$$

  - Nonlinear equation, used parameterization

$$\alpha(x) = \frac{1-x}{(1+0.5x)^2}$$

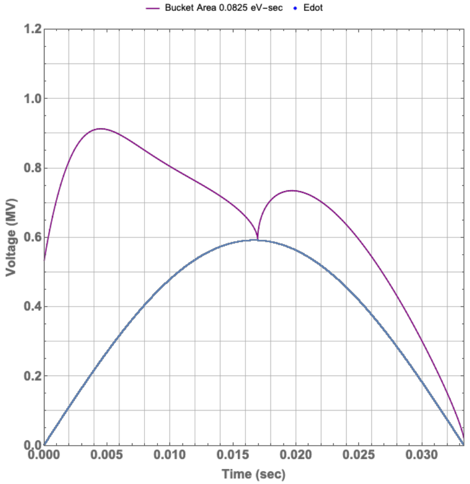
Nota Bene: This idea is not original to me! See S. C. Snowdon, Fermilab-TM-304, May 1971 for an earlier iteration of this same calculation

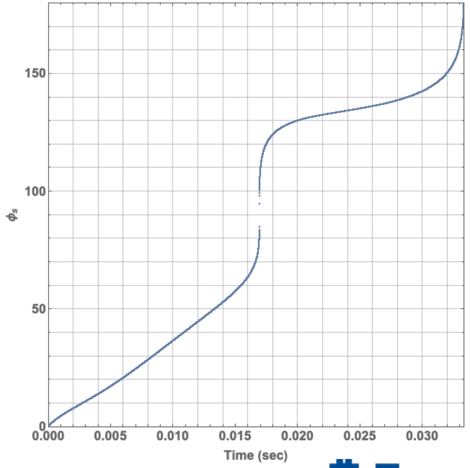
Including some measurement information

- Set the bucket area below transition
- Following Ostiguy & Lebedev(*), double the bucket area above transition

- Used Mathematica to do the root finding and solve for the accelerating phase and V_{rfsum}

- Getting closer
  - peak around 5 msec
  - Falls off to transition
  - Comes up again above transition



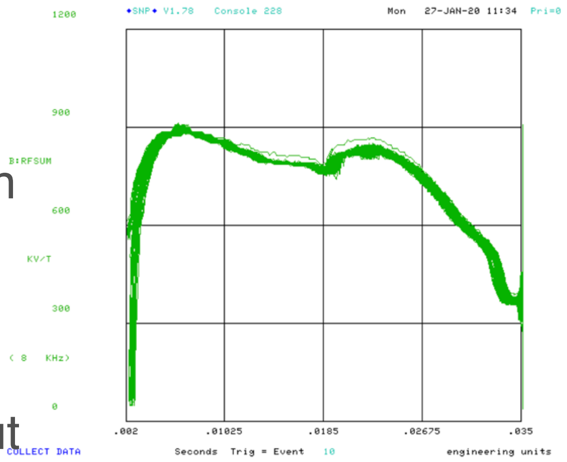


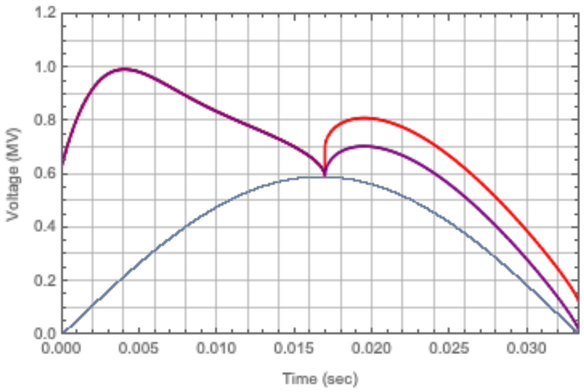
*J.-F. Ostiguy, *et al.*, "Modeling Longitudinal Dynamics in the Fermilab Booster Synchrotron", FERMILAB-CONF-16-162-AD, Proceedings of the 7th International Particle Accelerator Conference (IPAC2016): Busan, Korea May 8-13 2016. http://lss.fnal.gov/archive/2016/conf/fermilab-conf-16-162-ad.pdf

One more term

- Above transition, the longitudinal impedance of the Booster magnets induces a voltage of the opposite sign of the longitudinal restoring force
  - Need additional voltage above transition

- Assuming ~uniform frequency response (not perfect but maybe reasonable)
  - calculate an average value
  - For beam intensity of 4.5e12





J. E. Griffin, "Aspects of operation of the Fermilab Booster RF system at very high intensity", FERMILAB-TM-1968, April 1996, https://lss.fnal.gov/archive/test-tm/1000/fermilab-tm-1968.pdf

TM 1968 Comparison

- Discussion of how to operate Booster RF for 5e13 per pulse
  - Gap Voltage
  - Beam Loading Compensation
  - Longitudinal impedance voltage > accelerating voltage

- Able to duplicate the figure for the gap voltage, given the bucket area

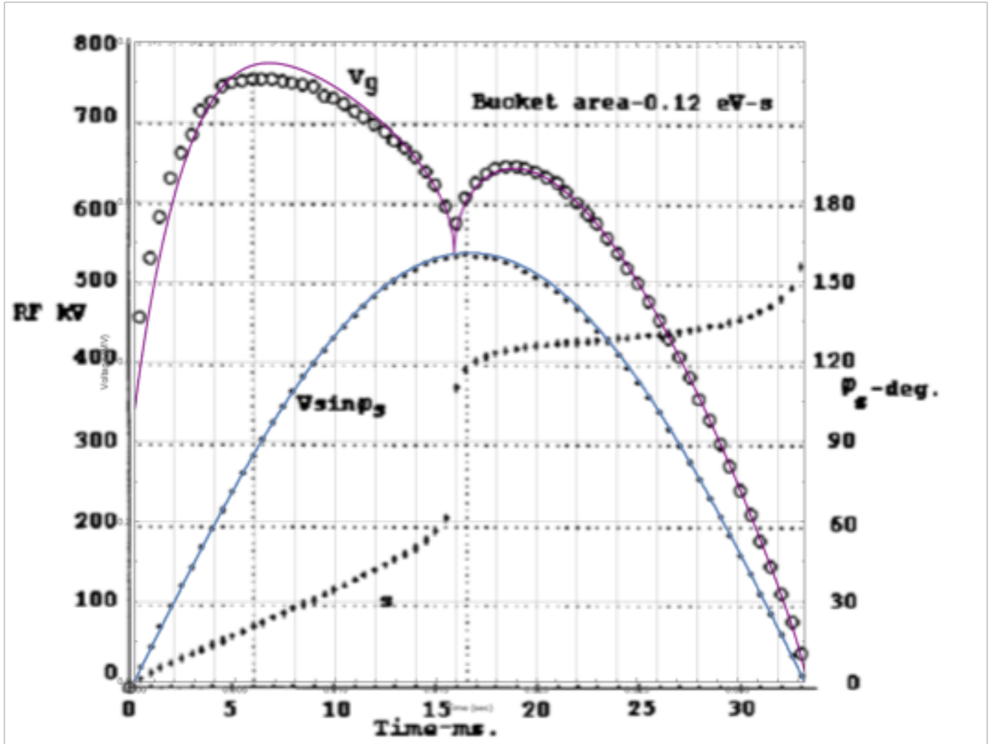
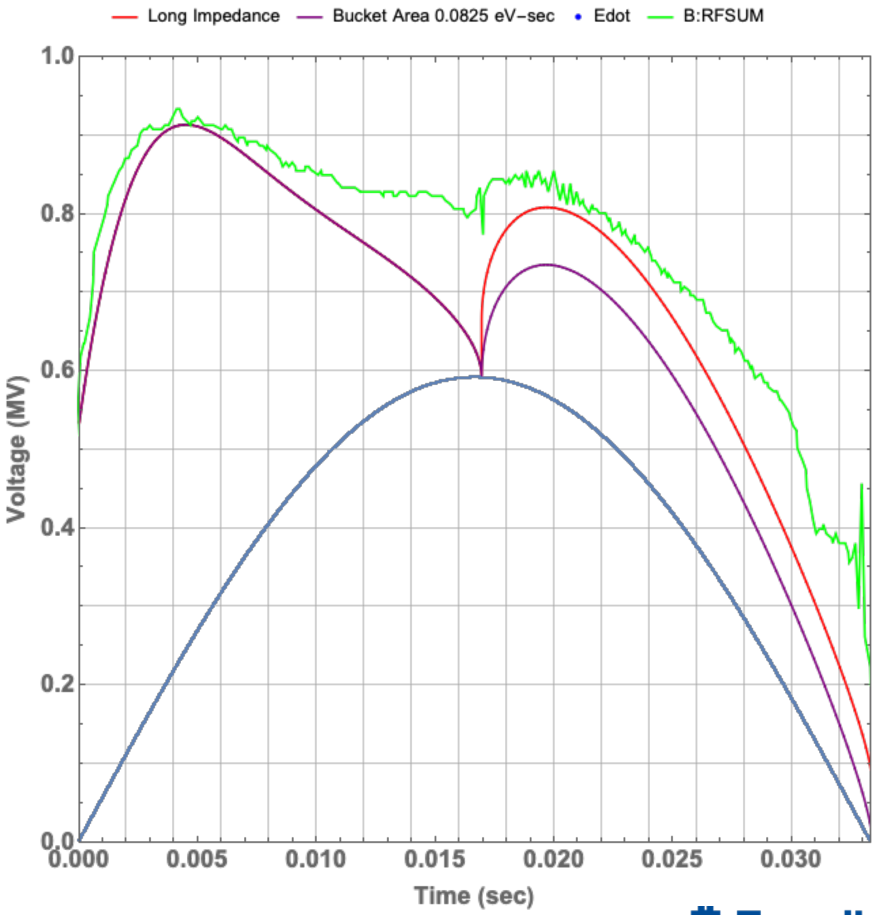


Figure 5

J. E. Griffin, "Aspects of operation of the Fermilab Booster RF system at very high intensity", FERMILAB-TM-1968, April 1996, https://lss.fnal.gov/archive/test-tm/1000/fermilab-tm-1968.pdf

Current Booster RFSum Curve

- Tuned bucket area to peak of operational curve on February 12 09:45 am (single snapshot)
  - 0.0825 eV-sec
- Caveats: working on understanding absolute calibration of B:RFSUM
  - on Jan 8 swapped BRF20 in for BRF11 and it went down by 60 kV!
  - Rephased BRF20 Feb 10
    - Peak around 925 kV (up about 40 kV)
- This approach reproduces the general shape of the curve and can be used to predict requirements for PIP-II

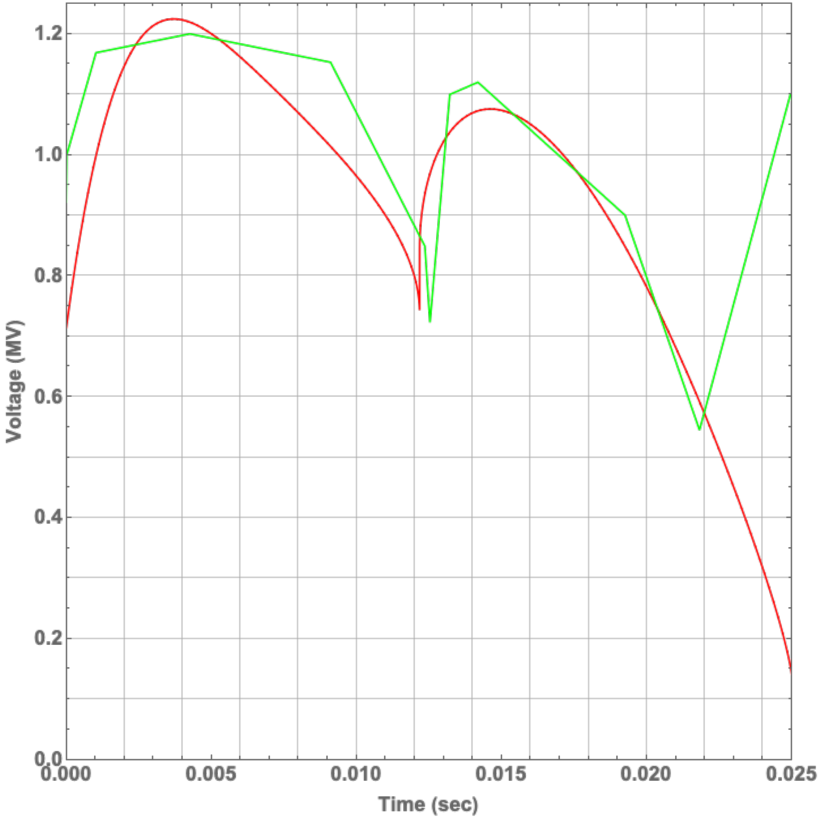


PIP-II Booster RFSum Curve

- For the PIP-II era
  - 0.14 eV-sec bucket area before transition
    - 1.5x greater above transition (PIP-II CDR)
  - 6.5e12 for long impedance contribution
  - Red Curve

- Simulation studies* lead to green curve
  - though have a minor misunderstanding in importing data in that I don't match transition time!
  - the simulation includes bunch rotation at the end of the cycle

- Peak 1.22 MV at 4 msec



*C.Y. Tan, *et al.*, "The required number of wide bore cavities for PIP-II", January 2020, https://beamdocs.fnal.gov/AD-private/DocDB/ShowDocument?docid=7879

Fermilab

Accelerating Phase PIP-II era